

DETECTION SYSTEM FOR CHEMICAL-MECHANICAL PLANARIZATION TOOL

TECHNICAL FIELD

[0001] The present invention generally relates to the chemical mechanical planarization of semiconductor wafers, and more particularly relates to the detection of an end point of a chemical mechanical planarization process.

BACKGROUND

[0002] A flat disk or "wafer" of single crystal silicon is the basic substrate material in the semiconductor industry for the manufacture of integrated circuits. Semiconductor wafers are typically created by growing an elongated cylinder or boule of single crystal silicon and then slicing individual wafers from the cylinder. The slicing causes both faces of the wafer to be extremely rough. The front face of the wafer on which integrated circuitry is to be constructed must be extremely flat in order to facilitate reliable semiconductor junctions with subsequent layers of material applied to the wafer. Also, the material layers (deposited thin film layers usually made of metals for conductors or oxides for insulators) applied to the wafer while building interconnects for the integrated circuitry must also be made a uniform thickness.

[0003] Integrated circuits manufactured today are made up of literally millions of active devices such as transistors and capacitors formed in a semiconductor substrate. Integrated circuits rely upon an elaborate system of metallization in order to connect the active devices into functional circuits. A typical multilevel interconnect 100 is shown in FIG. 1. Active devices such as MOS transistors 107 are formed in and on a silicon substrate or well 102. An interlayer dielectric (ILD) 104, such as SiO_2 is formed over silicon substrate 102. ILD 104 is used to electrically isolate a first level of metallization that is typically aluminum (Al), with copper (Cu) increasing in popularity, from the active devices formed in substrate 102 to interconnections 108 of the first level of metallization. In a similar manner metal vias 112 electrically couple interconnections 114 of a second level of metallization to interconnections 108 of the first level of metallization. Contacts 106 and vias 112 typically comprise a metal

116 such as tungsten (W) surrounded by a barrier metal 118 such as titanium-nitride (TiN). Additional ILD/contact and metallization layers may be stacked one upon the other to achieve the desired interconnections. The ILD/contact and metallization layers may be formed, for example, using a dual damascene process.

[0004] Planarization is the process of removing projections and other imperfections to create a flat planar surface, both locally and globally, and/or the removal of material to create a uniform thickness for a deposited thin film layer on a wafer. Semiconductor wafers are planarized or polished to achieve substantially smooth, flat finish before performing process steps that create the integrated circuitry or interconnects on the wafer. A considerable amount of effort in the manufacturing of modern complex, high density multilevel interconnects is denoted to the planarization of the individual layers of the interconnect structure. Nonplanar surfaces create poor optical resolution of subsequent photolithography processing steps. Poor optical resolution prohibits the printing of high-density lines. Another problem with nonplanar surface topography is the step coverage of subsequent metallization layers. If a step height is too large there is a serious danger that open circuits will be created. To this end, chemical-mechanical planarization (CMP) tools have been developed to provide controlled planarization of both structured and unstructured wafers.

[0005] CMP consists of a chemical process and a mechanical process acting together, for example, to reduce height variations across dielectric region, clear metal deposits in damascene processes or remove excess oxide in shallow trench isolation fabrication. The chemical-mechanical process is achieved with a liquid medium containing chemicals that react with the front surface of the wafer when it is mechanically stressed during the planarization process.

[0006] In a conventional CMP tool for planarizing a wafer, a wafer is secured in a carrier connected to a shaft. The shaft is typically connected to mechanical means for transporting the wafer between a load or unload station and a position adjacent to a polishing pad mounted to a rigid or flexible platen or supporting surface. Pressure is exerted on the back surface of the wafer by the carrier in order to press the front surface of the wafer against the polishing pad, usually in the presence of slurry. The wafer and/or polishing pad are then moved in relation to each other via motor(s) connected to the shaft and/or supporting surface in order to remove material in a planar manner from the front surface of the wafer.

[0007] It is often desirable to monitor the front surface of the wafer during the planarization process. One known method is to use an optical system that monitors the front surface of the wafer in situ by positioning an optical probe under the polishing pad. Laser interferometry, signal template matching and multifrequency analysis techniques, as well as others, are known monitoring methods. The signal from the probe may be transmitted and received through an opening in the polishing pad. The opening in the polishing pad may be filled with an optically transparent material, or "window", in order to prevent polishing slurry or other contaminants from being deposited into the probe and obscuring the optical path to the wafer. The data from the optical system is typically analyzed by a control system to determine the current condition of the front surface of the wafer. It is possible to terminate the planarization process (call end-point) once the front surface of the wafer has reached a desired condition. An optical system may be used to compensate for drifts in the planarization process, variability in the associated consumables (polishing pads and slurries), and variability in the thickness of incoming wafers.

[0008] A reliable end-point detection system is critical for maintaining the optimum CMP process. The end-point system detects the point in the planarization process when the overburden being polished is removed everywhere across the wafer. Excessive removal of overburden from the front surface of the wafer, whether a raw sheet film, or an STI, metal or dielectric layer structure on the front wafer surface, may damage the wafer.

[0009] Accordingly, it is desirable to monitor a surface of a wafer during a planarization process and have a methodology for accurate detection. In addition, it is desirable to take measurements frequently and having a small spot size for higher sensitivity in detecting small residuals. It is also beneficial to be able to identify when the material being removed approaches a clearing stage to prepare for ending the CMP process. Furthermore, other desirable features and characteristics of the present invention will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and the foregoing technical field and background.

BRIEF SUMMARY

[0010] A method is provided for endpoint detection in a chemical mechanical planarization (CMP) process. Reflectance spectra data is taken periodically in different areas of a surface of a semiconductor wafer during a chemical mechanical planarization process. Three different reflectance spectra are identified to determine a status of the CMP process. A first reflectance spectra data corresponds to light reflected predominately from a layer of material on the surface of the semiconductor wafer. A second reflectance spectra corresponds to the layer of material being thinned such that the second reflectance spectra is modified by an underlying layer of material. A third reflectance spectra corresponds to light reflected predominately from the underlying layer of material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The present invention will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and

[0012] FIG. 1 is a greatly expanded cross section view of a semiconductor chip;

[0013] FIG. 2 is a greatly expanded cross section view of an interconnect in a semiconductor chip;

[0014] FIG. 3 is a simplified cross section view of an apparatus used to practice the present invention;

[0015] FIG. 4 is a reflectance spectra of a barrier layer such as Ta or TaN at the start of a CMP process;

[0016] FIG. 5 is a reflectance spectra of the barrier layer being cleared away exposing a dielectric layer such as silicon dioxide;

[0017] FIG. 6 is an intermediate reflectance spectra that occurs as a barrier layer is thinned in accordance with the present invention;

[0018] FIG. 7 is a normalized reflectance spectra for the case when the measurement produces a reflectance spectra that is predominately from light reflected from the targeted material;

[0019] FIG. 8 is a normalized reflectance spectra for the case when the barrier layer is thinned during the CMP process and the reflected light is modified by the underlying layer of material;

[0020] FIG. 9 is a normalized reflectance spectra for the case when the barrier layer is removed and the reflected light is predominately from the underlying dielectric layer; and

[0021] FIG. 10 is a flow diagram of an exemplary process in accordance with the present invention.

DETAILED DESCRIPTION

[0022] The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description.

[0023] CMP of copper will become one of the most common and critical chemical mechanical planarization processes when the copper interconnect technology starts to dominate the fabrication of integrated circuits. FIG. 2 illustrates some of the potential problems if excessive overburden is removed, in this case a barrier layer 203, from the front surface of a wafer. At time T1 a layer of deposited copper 200 remains on the wafer. The copper layer is removed with a CMP step exposing barrier layer 203. In general, barrier layer 203 is deposited before copper 200. Barrier layer 203 forms a layer on the bottom and sidewalls of a cavity, via opening or trench. Barrier layer 203 is also on the wafer surface underlying copper 200. For

example, Tantalum (Ta) or Tantalum Nitride (TaN) is often used to form barrier layer 203. Barrier layer 203 typically has good adhesive qualities to silicon dioxide 201 and copper 200.

[0024] A second CMP step removes barrier layer 203 on the surface of the wafer. Ideally, the CMP step should terminate at time T2 or just slightly thereafter for an optimum planarized surface. However, if the planarization process is not terminated quickly enough, excessive removal of copper in the interconnects 202 may occur as shown at time T3. The dishing of the copper interconnects 202 occurs because the copper is softer than silicon dioxide 201 and is therefore removed at a faster rate.

[0025] End-point detection and monitoring is required for barrier layer 203 during a CMP step due to the variations in the incoming thickness distribution of barrier layer 203 as well as microstructural variations in the deposited barrier film. This may result in nonuniform clearing of barrier layer 203 across the front surface of the wafer. Several problems exist with conventional in situ monitoring techniques that limit their ability to accurately detect the clearing of barrier layer 203. In particular, it is very difficult to detect an end point when comparing reflectance spectra of barrier layer 203 and reflectance spectra of a dielectric layer such as silicon dioxide 201.

[0026] Some conventional monitoring systems use a laser interferometer positioned below a rotating polishing pad. However, this type of monitoring system can only take measurements while the laser and optical path through the polishing pad are in alignment with the front surface of the wafer. This situation creates a very narrow time-period during each rotation of the polishing pad that measurements can be taken. The narrow time-period during each rotation of the polishing pad that measurements can be taken. The narrow time-period and the delay between time-periods for taking measurements created by the rotating polishing pad greatly diminish the capabilities of the monitoring system.

[0027] In addition, some conventional systems tend to measure a relatively large spot, or integrate a number of large spot, or integrate a number of large spots (smear measurement), on the wafer's surface to increase the surface area of the wafer being monitored. However, these measurements create a system with very poor sensitivity that cannot distinguish high metallization density from mere residual metal. Improved sensitivity is required to detect

residuals on the wafer's surface that are on the order of the spot size, but may influence the quality of the planarization process.

[0028] An apparatus for practicing the present invention will now be discussed with reference to FIG. 3. During a planarization process, a wafer 100 may be transported by a carrier 301 to a position adjacent and substantially parallel to a working surface or polishing pad 309. The front surface of the wafer 100 is pressed against the polishing pad 309 fixed to a supporting surface 211, preferably in the presence of a slurry (not shown). The front surface of the wafer 100 is planarized by generating relative motion between the front surface of the wafer 100 and the polishing pad 309 thereby removing material from the front surface of the wafer 100.

[0029] The apparatus includes a plurality of probes 305a-c positioned beneath the polishing pad 309 to transmit light to, and receive reflected light from, the front surface of the wafer 100. Three probes 305a-c are illustrated in FIG. 3, however, any number of probes may be used. The greater the number of probes, the faster a complete scan of the wafer may generally be taken, but each additional probe increases the expense and complexity of the system. The probes 305a-c are preferably bifurcated to allow separate optical paths for the transmitted and reflected light to, and receive reflected light from, a particular annular band on the front surface of the wafer 100. If an orbital CMP tool is used having a relatively small orbital radius, each probe 305a-c may be used to monitor a single annular band. The annular bands in such an orbital CMP tool may be made to overlap to ensure the entire front surface of the wafer 100 may be altered by a multizone carrier 301.

[0030] The carrier 301 is preferably rotated about its central axis as it presses the front surface of the wafer 100 against the polishing pad 309 during the planarization process. The rotational speed of the carrier 301 is preferably selected to optimize the planarization process. The optimum rotational speed for the planarization process may be determined through computer models or by empirical means. Rotational speed of about 12 rpm for the carrier 301 have been found to produce satisfactory planarization results while permitting the transmittance and reception of reflected light from the front surface of the wafer 100. The carrier 301 may also be moved along the polishing pad 309 to enhance the planarization process of the wafer 100.

[0031] The carrier 301 may be adapted to permit biasing the pressure exerted on different areas of the back surface of the wafer 100. Areas of the back surface of the wafer 100 receiving a higher (or lower) pressure will typically increase (or decrease) the removal rate of material from corresponding areas on the front surface of the wafer 100. Removal rates of material from planarization processes are typically substantially uniform within concentric annular bands about the center of the wafer, but often differ greatly from band to band. To correct for this common problem, the carrier 301 is preferably capable of exerting different pressures in a plurality of different areas while maintaining a uniform pressure within each area. Since removal rates for planarization processes tend to be uniform within concentric bands on the front surface of the wafer 100, the carrier 301 is ideally able to apply a uniform pressure over each concentric band on the back surface of the wafer 100. In addition, since removal rates tend to differ from band to band on the front surface of the wafer 100, the carrier 301 is also ideally able to apply different pressures over different bands on the back surface of the wafer 100. Examples of such carriers are disclosed in U.S. Patent No. 5,882,243; U.S. Patent No. 5,916,016; U.S. Patent No. 5,941,758; and U.S. Patent No. 5,964,653 and are hereby incorporated by reference. The greater the number of concentric annular bands, the greater the process flexibility in adjusting the carrier 301 to the problems encountered in the planarization process. However, the complexity and cost of the carrier also increases as the number of adjustable bands increases. A carrier with three (3) adjustable concentric pressure bands is expected to give you improved process flexibility while keeping the complexity of the carrier to a manageable level. Since the need for improved process results is almost certainly going to increase in the future, the preferred number of controllable bands within the carrier will also likely increase in the future.

[0032] A simplified view of one possible multizone carrier 301 is illustrated in FIG. 3. Carrier 301 has three concentric plenums: a central 303a, intermediate 303b and peripheral 303c plenum. A flexible membrane 314 provides a surface for supporting the wafer 100 while an inner 315 and an outer 316 ring provides barriers for separating the plenums 303a-c. The pressure within the central 303a, intermediate 303b and peripheral 303c plenums may be individually communicated through passageways 304a-c by respective controllable pressure regulators 313a-c connected to a pump 312. A rotary union 302 may be used in communicating the pressure from the pump 312 and pressure regulators 313a-c to their respective plenums

303a-c if the carrier 301 is rotated. Thus, each concentric plenum 303a-c may be individually pressurized to create three concentric bands to press against the back surface of the wafer 100. Each plenum 303a-c may therefore have a different pressure, but each concentric band will therefore have a uniform pressure within the band to press against the back surface of the wafer 100.

[0033] A supporting surface 211 may be used to support the abrasive surface or polishing pad 309. The supporting surface 211 may be a rigid substantially planar surface comprising aluminum, stainless steel, ceramic, titanium, polymer or other such rigid, non-corrosive material. Alternatively, the supporting surface 211 for a polishing pad 309. A slurry delivery system (not shown) is preferably incorporated into the supporting surface 211 for delivery of slurry onto the polishing pad 309.

[0034] The supporting surface 211 may be connected to a motion generator 500 for creating relative motion between the front surface of the wafer 100 and the polishing pad 309. Various motions for the supporting surface 211 are already known. For example, U.S. Patent No. 5,498,196 shows an example of a rotational CMP tool; U.S. Patent No. 5,692,947 shows an example of a linear belt system; U.S. Patent No. 5,707,274 shows an example of a rotary drum system; and U.S. Patent No. 5,554,064 shows an example of an orbital tool, all of which are hereby incorporated by reference.

[0035] A multiprobe metrology instrument, e.g. a multiprobe end-point detection system 308, may be used to analyze data from the front surface of a wafer 100. Multiple probes allow samples to be taken at a desired density across the face of the wafer 100 in a shorter time than a single probe system, but increase the complexity of the system. This is accomplished since additional probes prevent or shorten the time when there are no probes under the front surface of the wafer 100 and may even allow multiple points to be sampled substantially simultaneously. It is highly desirable to take samples at a desired spatial density across the entire surface of the wafer 100 (a "scan") as quickly as possible to obtain the best possible data to analyze. The surface of the wafer 100 changes rapidly during the planarization process and a long interval between samples will result in the early measurement not accurately reflecting the condition of the wafer 100 when the later measurements are taken. Interpolation, extrapolation

or modeling software may be used to make estimates that compensate for temporal variations in samples, but the preferred method is to complete the scan as quickly as possible.

[0036] As a specific example, a short scan time may help avoid dishing or erosion in a barrier layer chemical mechanical planarization process used in forming interconnect. Once an area has been cleared of the barrier material, a scan of the entire wafer is preferably completed with the desired resolution within the time necessary to prevent excessive erosion or dishing of features in the cleaned area. Measurements are most important once an area has cleared to make sure the planarization process stops before that area or any other area experiences erosion or over-polishing.

[0037] The multiprobe end-point detection system 308 may be used to determine areas on the front surface of the wafer 100 that need an increase or decrease in material removal rate. The areas that need an increase or decrease in material removal rate will typically take the form of concentric rings about an annular central region on the front surface of wafer 100.

[0038] A multiprobe end-point detection system 308 is advantageous in CMP tools where a wafer does not remain over the same area of a polishing pad, as in a conventional rotational CMP tool. Multiple probes may be used to reduce the amount of time when no probe is under the wafer or may be used to increase the number of points sampled when more than one probe is under the wafer. A multiprobe end-point detection system 308 is also advantageous in systems where the wafer remains substantially over the same area of a polishing pad, as in a conventional orbital system. As illustrated in FIG. 3, the probes 306a-c may be positioned where they are always, or almost always, under the wafer 100 thereby allowing multiple probes 306a-c greatly reduces the time necessary to complete a scan and greatly increases the accuracy of the analysis of the front surface of the wafer 100 by limiting temporal difference in the samples.

[0039] Referring still to FIG. 3, an emitter or flash lamp 317 may be used to initiate a light signal to travel through one or more fiber optical cables 307a-c. One or more probes 306a-c are preferably positioned as close as possible to a transparent area 305a-c to enhance the optical communication. The reflected light signal from the wafer 100 may be captured by a probe 306a-c and routed to a metrology instrument 318, such as spectrometer, via fiber optic cables

307a-c. The invention may be practiced with a variety of probes, flash lamps and fiber optical cables that are known in the art.

[0040] While measurement averaging or integration over a large area may be used to collect samples, a flash lamp 317 allows high-speed discrete measurements to be taken. Discrete measurements provide finer spatial resolution and are capable of detecting smaller residuals on the front surface of the wafer 100. The light signal is preferably a broad band spectrum of light so that the intensity of the reflected light signal may be analyzed at multiple wavelengths. In one embodiment, the spectrum preferably includes light between 300 and 800 nm in wavelength. As a specific example, a Xe flash lamp 317 may be used to generate the light signal. Although a pulsed light system is preferred, using a non-pulsed light system is also a viable alternative.

[0041] The flash duration of the flash lamp 317 should be as short as possible to minimize the amount of relative motion between the surface of the wafer and the flash lamp 317 and probe 306a-c during signal collection. Relative motion between the surface of the wafer 100 and the probe will create a smear effect and decrease the sensitivity of the measurement if the illumination were to endure over the relatively large duty cycle period of a grating spectrometer. The flash duration does need to be long and intense enough, however, to provide enough signal intensity for the probes 306a-c to collect the reflected light from the surface of the wafer 100. The flash duration is preferably less than about ten microseconds.

[0042] The flash is optimally repeated as quickly as possible in order to gather the greatest amount of sample data. However, two factors limit the usefulness of extremely fast sampling rates. The first is that each flash provides a tremendous amount of data that must be quickly analyzed. Data that has been gathered, but that cannot be timely analyzed does not benefit the system. The second factor is that some time must be allowed to pass between measurement in order to relative motion between the front surface of the wafer 100 and the probes 306a-c to move the measurement location. The measurements are preferably evenly distributed, and as close as possible, across the front surface of the wafer 100.

[0043] The spot size of light from the flash lamp 317 is preferably slightly larger than the largest feature that is supposed to remain on the surface of the wafer 100. This will prevent a

fully planarized area from giving a false reading indicating that residuals remain. This could happen if a measurement were taken over a large feature with a spot size smaller than the large feature. On the other hand, a spot size that is too big may miss residuals that are smaller than the spot size. The optimum spot size is larger than the largest feature while also being smaller than the smallest residual it is required to detect. As feature sizes continue to decrease and the requirements for semiconductor manufacturing continue to become more stringent, the optimum spot size will decrease. A spot size of one to three mm in diameter acceptable for the most current semiconductor manufacturing requirements with smaller spot sizes likely required in the future.

[0044] There are preferably enough probes properly positioned in the CMP tool to allow sampling across the entire front surface of the wafer 100 during the planarization process. Typical orbital CMP tools, due to the small relative movements between the front surface of the wafer 100 and the polishing pad 309, need multiple probes that preferably have a slight overlap of coverage to insure all areas on the front surface of the wafer 100 are sampled. Each probe in a conventional orbital CMP tool, with a rotating carrier 301, will examine an annular band on the front surface of the wafer 100 approximately the width of the diameter of the orbit. Thus, all the data for a particular annular band on the front surface of the wafer 100 in a conventional orbital CMP tool comes from a single probe thereby simplifying the analysis of the data.

[0045] The metrology instrument 318, preferably a grating spectrometer(s), accepts the incoming reflected light signal and converts the light signal into data indicating the intensity of the reflected light a plurality of different wavelengths. The data may then be transmitted to a control system 311 for analysis. The control system 311 is able to determine the condition of the front surface of the wafer 100 from the data. A number of numerical methods may be used to determine when the planarization process should be terminated, i.e. end-point called. For example, end-point may be called after a predetermined over-polish time has occurred starting from the time a predetermined percentage of measurements show an absence of a barrier material. The over-polish time ensures a complete clearing of the barrier material. The over-polish time and the percentage of measurements showing an absence of barrier material are preferably determined empirically due to variations from planarization process to planarization process.

[0046] Another method of analyzing the data compares the clearing time for different concentric areas on the front surface of the wafer 100. This method may be simplified when each probe monitors a particular, possibly overlapping, concentric band as would be the case when used with orbital CMP tools with a relatively small orbital radius. For example, probes 306a-c below areas that clear first indicate bands that are being polished too quickly in comparison to other bands. Corrective action may then be taken for that wafer 100 or the information may be used to improve the planarization process for incoming wafers.

[0047] The control system 311 may make immediate adjustments to the planarization process based on the analysis of the measurements. For example, increasing or decreasing the pressure on the back surface of the wafer 100 during the planarization process has been found to increase or decrease, respectively, the removal rate at the periphery of the wafer 100 with respect to the center of the wafer 100. As another example, more or less slurry may be distributed near areas that have been found to need increased or decreased, respectively, removal rates. As yet another example, the rotation speed of the carrier 301 may be increased or decreased, respectively, removal rates. As yet another example, the rotation speed of the carrier 301 may be increased or decreased to increase or decrease, respectively, the removal rate at the periphery of the wafer 100. However, the preferred method is to use a multizone carrier 301 to alter the removal rate at different areas of the front surface of the wafer 100. Specifically, the pressure may be increased or decreased in zones over areas that need an increase or decrease in material removal rate, respectively, on the front surface of the wafer 100. In addition, the results from planarized wafers 100 may be used to change the process parameters for incoming wafers. This allows process drift within the planarization process to be detected and compensated for as it happens.

[0048] To determine the condition of the front surface of the wafer 100, the location for each measurement should be known. One possible method is to track only the radial position for each measurement and take at least one measurement at various radial positions in find enough increments to provide a desired sampling resolution. This method assumes that each measurement accurately represents the condition of the wafer 100 at every point having the same radial position. Since wafers 100 generally have bands that planarize at approximately the same rate, this method provides a simple approximation of the condition of the front surface of

the wafer 100. In this manner, measurements may be taken across the front surface of the wafer 100 at a desired spatial resolution that prevents a problem area larger than the desired resolution from going unobserved.

[0049] Various devices may be used to track the location of the measurement on the front surface of the wafer 100. For example, an encoder 320 may be used to track the position of the carrier 301 (and thus the wafer) and transmit this information via communication line 319 to the control system 311. In a similar manner, an encoder 321 may be used to track the position of the supporting surface 211 (and thus the probes) and transmit this information via communication line 322 to the control system 311. The wafer 100 may need to be firmly held in the carrier 301 to prevent the wafer 100 from spinning and randomizing its orientation. For example, the wafer 100 may be held in place by applying suction to the back surface of the wafer 100 through the membrane 314 or by creating a tacky bottom surface for the membrane 314. The control system 311 thus has the information necessary to match the data from the metrology instrument 318, preferably a spectrometer, with the data's corresponding location on the front surface of the wafer 100. Alternatively, modeling software for the mechanical mechanisms that cause the relative motion between the wafer 100 and the polishing pad 308 may also be used to predict the location of each measurement on the front surface of the wafer 100. Modeling software is also useful in determining desirable motions for the carrier 301 and supporting surface 211, and thus the wafer 100 and probes, that will produce a pattern of measurements as evenly distributed as possible. Small adjustments to the desired relative motion between the wafer 100 and the polishing pad 309 may be made to improve the distribution of measurements while having only a minimum impact on the planarization process. An evenly distributed pattern may shorten the time of a scan by requiring the minimum number of measurements and the least amount of data processing. However, the measurement locations do not have to be evenly distributed, but the largest space between measurements is preferably smaller than the targeted residual detection capability.

[0050] Alternatively, the measurements may be analyzed until the largest possible remaining residual is of a predetermined size. Once all the remaining residuals are of the predetermined size or smaller, the wafer 100 may be planarization for an additional time (over-polish time) to remove the remaining residuals. The additional planarization time may be found by empirically

determining the maximum amount of time necessary to planarize away residuals of the predetermined size.

[0051] All of the described techniques help to control the rate and uniformity of material removal with the proper input. The problem for some chemical mechanical planarization processes is the determination of the exact status at any point in time. For example, in many CMP processes the transition from having a material present on the wafer surface to the material being cleared away will give many indicators over time that allow precise determinations to be made. For other CMP processes it is very difficult to tell when the material is cleared away.

[0052] One such chemical mechanical planarization process is removing a barrier layer having an underlying dielectric layer. FIG. 4 is a reflectance spectra 400 of a barrier layer such as Ta or TaN at the start of a CMP process. The Y-axis is intensity and the X-axis is the light wavelength. As shown, a broadband spectrum of light is used having a wavelength ranging from approximately 200 nanometers to 800 nanometers. Three different reflectance spectra are shown because three probes were used to take the measurements. Each probe took measurements at different locations on the wafer. Notice that peaking occurred at wavelengths slightly less than 500 nanometers. The reflectance spectra generated at the start of the CMP process comprises light reflected predominately from the barrier material. All of the following reflectance spectra discussed hereinbelow will be represented similarly.

[0053] FIG. 5 is a reflectance spectra 500 of the barrier layer (Ta or TaN) being cleared away exposing a dielectric layer such as silicon dioxide. Continued polishing after the barrier layer has been removed can produce problems such as the dishing effect described hereinabove that occurs when other materials are exposed and removed at a faster rate than the dielectric layer. Another problem is too much dielectric removal. As described in FIG. 4, three probes were used to take measurements, each probe measured different areas of the wafer. Note that reflectance spectra 500 of the dielectric layer have a characteristic very similar to the barrier layer. Even though reflectance spectra 400 of FIG. 4 and reflectance spectra 500 of FIG. 5 look similar, reflectance spectra 500 of FIG. 5 comprises light reflected predominately from the dielectric material. As shown, the peaking of reflectance spectra 500 occurs in almost an identical location at slightly less than 500 nanometers. Reliably detecting the difference

between the two reflectance spectra has proven less than adequate for this situation. The result is poor end point detection that produces a wide process variance including both under and over polishing.

[0054] FIG. 6 is an intermediate reflectance spectra 600 that occurs as a barrier layer is thinned in accordance with the present invention. In particular, the layer being removed in FIG. 6 comprises Ta or TaN. Intermediate reflectance spectra 600 is substantially different from the case of reflected light that is predominately from the barrier material as shown in FIG. 4 or the case of reflected light that is predominately from the underlying dielectric layer as shown in FIG. 5. Of note is the dip in magnitude that occurs between a wavelengths of 550 to 600 nanometers. It is believed that the characteristic intermediate reflectance spectra 600 occurs for refractory metals and alloys thereof such as Ti, Cr, Mo, W, Rh, Ru, Re, WSi, and WNxCy although all have not been tested at this time. It is also possible for this characteristic intermediate reflectance spectra to occur for other materials with equal usefulness to a semiconductor manufacturing process.

[0055] The theory behind this discovery is that the material as it is thinned enters a transparent phase to the measurement light or light pulse. In other words, the reflected light is modified by both the surface material (barrier material) upon which the light impinges and the underlying layer (dielectric material). A beneficial factor in using intermediate reflectance spectra 600 is that it occurs before all the surface material is removed and that it is substantially different from the preceding and following reflectance spectra measured during the chemical mechanical planarization process. For example, a layer of Ta or TaN deposited to form a barrier layer in a copper interconnect is deposited having a thickness of approximately 500 angstroms. Performing a chemical mechanical planarization process to remove the barrier layer on the surface of the wafer has found intermediate reflectance spectra 600 to occur when the barrier layer has been thinned to approximately 100 angstroms. The average thickness when this transparent phase occurs and the detectable range around the median should be characterized for each process and material. In this example, intermediate reflectance spectra 600 is highly desirable because it occurs immediately before the all the material is removed or cleared. Thus, allowing a clear signal to be propagated to the CMP system that the clearing phase will be approaching and to begin looking for the characteristic reflectance spectra

corresponding to the material being cleared away such that the underlying layer is exposed. This provides increased control in determining the end point of the process thereby preventing under or over polishing and providing a process control that is uniform from wafer to wafer and lot to lot.

[0056] Normalization of the reflectance spectra measured from the wafer is a technique that helps to distinguish the three different reflectance spectra. In one embodiment, the in situ measured reflectance spectra is normalized against a known (reference) reflectance spectra where the reflected light is predominately from the surface material being removed. Ideally, the known reflectance spectra used for normalization is taken from the wafer during the chemical mechanical planarization process at the beginning of the material removal process. FIG. 7 is a normalized reflectance spectra 700 for the case when the measurement produces a reflectance spectra that is predominately from light reflected from the targeted material being removed during the CMP process. As expected, normalized reflectance spectra 700 appear as an almost horizontal line since the measured reflectance spectra should be very similar to the reference reflectance spectra used for normalization. Normalized reflectance spectra 700 are shown having a wavelength in a range from 400 to 800 nanometers.

[0057] FIG. 8 is a normalized reflectance spectra 800 for the case when the barrier layer is thinned during the CMP process and the underlying layer of material modifies the reflected light. Note the dramatic difference when compared to normalized reflectance spectra 700 shown in FIG. 7. The intermediate reflectance spectra when normalized take a characteristic sinusoidal shape. The sinusoidal shape has two peaks and one minimum over the range shown. The detection of this change in the CMP process is very clear and can be acted upon in a time frame for accurately controlling an end point for the process.

[0058] FIG. 9 is a normalized reflectance spectra 900 for the case when the barrier layer is removed and the reflected light is predominately from the underlying dielectric layer. In general, normalized reflectance spectra 900 taken for the dielectric layer appears as a horizontal line having no significant minimum or maximum. Although normalized reflectance spectra 900 of FIG. 9 do differ from normalized reflectance spectra 700 of FIG. 7, the changes are not dramatic or substantial as the change shown in FIG. 8. Moreover, normalized reflectance spectra 800 of FIG. 8 differs significantly from both the normalized reflectance spectra 700 of

FIG. 7 and normalized reflectance spectra 900 of FIG. 9. Another benefit is that normalized reflectance spectra 800 are extremely useful in determining an endpoint when a thin layer of material is deposited and requires removal. This is a situation that may occur in the future as geometries continue to shrink. Also, normalized reflectance spectra are only one of many formats that can be used to distinguish the three different measured reflectance spectra described hereinabove. For example, fast Fourier transform analysis is another method that could be used to review the constituents of the reflectance spectra data being gathered during the CMP process.

[0059] An illustrative method for planarizing a front surface of a wafer 100 will now be described with reference to FIGs. 2, 3 and 6. The wafer 100 is placed in a carrier 301 (step 600) and transported adjacent a polishing pad 309. The carrier 301 holds the wafer 100 substantially parallel to the polishing pad 309 while the wafer 100 is pressed against the top surface of the polishing pad 309 (step 601). The carrier 301 may be rotated or otherwise moved in relation to the polishing pad 309 to assist in uniformly removing material from the front surface of the wafer 100. The supporting surface 211 and attached polishing pad 309 may also be moved in relation to the front surface of the wafer 100 and is preferably orbited. (step 602) The relative motion is necessary to remove material from the front surface of the wafer 100.

[0060] In an embodiment for the manufacture of copper interconnect a groove, trench, or via is etched into dielectric layer 201. Barrier layer 203 is deposited on a surface of the semiconductor wafer such that the bottom and sidewalls of the grooves, trenches, or vias are covered. Copper 200 is then deposited on the surface covering barrier layer 203 and filling the grooves, trenches, or vias. A first CMP process is deployed such that copper 200 on the surface of the wafer is removed. The first CMP process is stopped when barrier layer 203 is reached. Copper 200 remains in the grooves, trenches, or vias level with barrier layer 203 on the surface of the wafer. A second CMP process for removing barrier layer 203 on the surface of the wafer follows.

[0061] An end-point system 308 with two or more probes 306a-c may be used to take measurements across the front surface of the wafer 100 during the planarization process. The end-point system 308 may reflect a light signal off the front surface of the wafer 100 using a flash lamp 317. In an embodiment of the system, a broadband spectrum of light is used having

a wavelength ranging from 300 nanometers to 800 nanometers. To prevent smearing, the light is pulsed for ten microseconds or less which corresponds to a wafer 100 traveling a small distance during the measurement. In an embodiment of the system, the spot size of the light pulse is made larger than the largest feature (containing the material being removed) to remain on the wafer after the CMP process.

[0062] A spectrometer 318 may be used to convert the reflected light into reflectance spectra data representing the intensity of the reflected light at a plurality of wavelengths. Linear encoders 320 and 321, computer modeling or other known methods for determining the physical location of the mechanical devices may be used to track the location of the carrier 301 and the supporting surface 211. This allows the location on the front surface of the wafer 100 to be determined for each measurement (step 603). A control system 311 may be used to analyze the measurements from the spectrometer 318 and the location of the measurements on the wafer 100 to determine the progress of the planarization process and the condition of the wafer 100 (step 604).

[0063] The progress of the planarization process is monitored and analyzed (step 604) for the three different characteristic spectra corresponding to the conditions where the light reflected back is predominately from barrier layer copper 200, the light reflected back is modified by the underlying dielectric layer, and the light reflected is predominately from dielectric 201. In particular, the intermediate reflectance spectra (light reflected back is modified by the underlying dielectric layer) are sought after which indicates the CMP process is nearing a clearing stage. Normalizing the reflectance spectra of the measurements taken during the CMP process would identify the three different characteristic reflectance spectra such as the sinusoidal shape of the normalized intermediate reflectance spectra.

[0064] The control system 311 may also be used to determine if an increased or decreased removal rate over a portion of the front surface of the wafer 100 is desirable (step 606). If the wafer 100 is being uniformly planarized, further measurements may be taken and analyzed (back to step 603). However, if the control system 311 determines the removal rate should be increased or decreased in particular areas, one or more planarization process parameters may be altered. For example, the down-force, slurry delivery profile, rotation speed of carrier, etc. may be adjusted to improve the planarization process. If a multizone carrier 301 is being used, an

increased or decreased pressure may be exerted on the back surface of the wafer 100 opposite areas on the front surface of the wafer 100 that required an increased or decreased removal rate respectively (step 607). After altering the planarization process, further measurements may be taken and analyzed (back to step 603) with appropriate steps as described above taken.

[0065] In an embodiment of the process, the end point detection step 605 begins when the intermediate reflectance spectra is detected. Once again, this occurs when the material being removed is thinned sufficiently where the underlying material modifies the reflected light. For example, the normalized reflectance data changes from a horizontal line to a sinusoidal shape. When this point is detected it will be known that the remaining material is within a specific range of thickness on the surface. The rate of material removal can also be calculated based on the initial thickness of the deposited material and the time it has taken to reach the intermediate reflectance spectra point. Several different steps can complete the CMP process. First, the CMP process can be completed after a predetermined time period after the intermediate reflectance spectra has been identified. The predetermined time is selected to ensure removal of all the remaining material. Second, the CMP process is continued with or without modifications to the CMP process in anticipation of receiving the reflectance spectra indicating that all the material has been removed. Upon receiving the reflectance spectra indicating clearing of the material, the endpoint has been detected and the CMP process is stopped. Finally, an overpolish step can be added after the reflectance spectra is detected indicating the material is cleared to ensure all the material is removed. In all of the cases, the end point detection using the intermediate step allows finer control of the CMP process to prevent under polishing and over polishing. If the control system 311 determines the wafer 100 has been sufficiently planarized (step 605) the wafer may be unloaded from the carrier (step 608) and removed from the CMP tool. The planarization results for this wafer 100 may be used to determine an improved planarization process for incoming wafers (step 609). This allows an improved down-force, slurry delivery profile, rotation speed of carrier, pressure within multizone carrier, relative motions between wafer 100 and polishing pad 309, etc. to be altered during the planarization process for incoming wafers to further improve the planarization process.-

[0066] While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the exemplary embodiment or exemplary embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope of the invention as set forth in the appended claims and the legal equivalents thereof.